N94- 33511

ENABLING PROPULSION MATERIALS FOR HIGH-SPEED CIVIL TRANSPORT ENGINES

524-07
12054

Joseph R. Stephens and Thomas P. Herbell
NASA Lewis Research Center
Cleveland, Ohio

First Annual High-Speed Research Workshop
May 14-16, 1991

ADVANCED MATERIALS CRITICAL TO HIGH-SPEED CIVIL TRANSPORT (HSCT)

NASA Headquarters and Lewis Research Center have advocated an Enabling Propulsion Materials Program (EPM) to begin in FY'92. The High Speed Research Phase I program which began in FY'90 has focused on the environmental acceptability of a High Speed Civil Transport (HSCT). Studies by industry, including Boeing, McDonnell Douglas, GE Aircraft Engines, and Pratt & Whitney Aircraft, and in-house studies by NASA concluded that NO_x emissions and airport noise reduction can only be economically achieved by revolutionary advancements in materials technologies. This is especially true of materials for the propulsion system where the combustor is key to maintaining low emissions and the exhaust nozzle is key to reducing airport noise to an acceptable level. Both of these components will rely on high temperature composite materials that can withstand the conditions imposed by commercial aircraft operations. The proposed EPM program will operate in conjunction with the HSR Phase I Program and the planned HSR Phase II program slated to start in FY'93. Components and subcomponents developed from advanced materials will be evaluated in the HSR Phase II Program.

E-6198

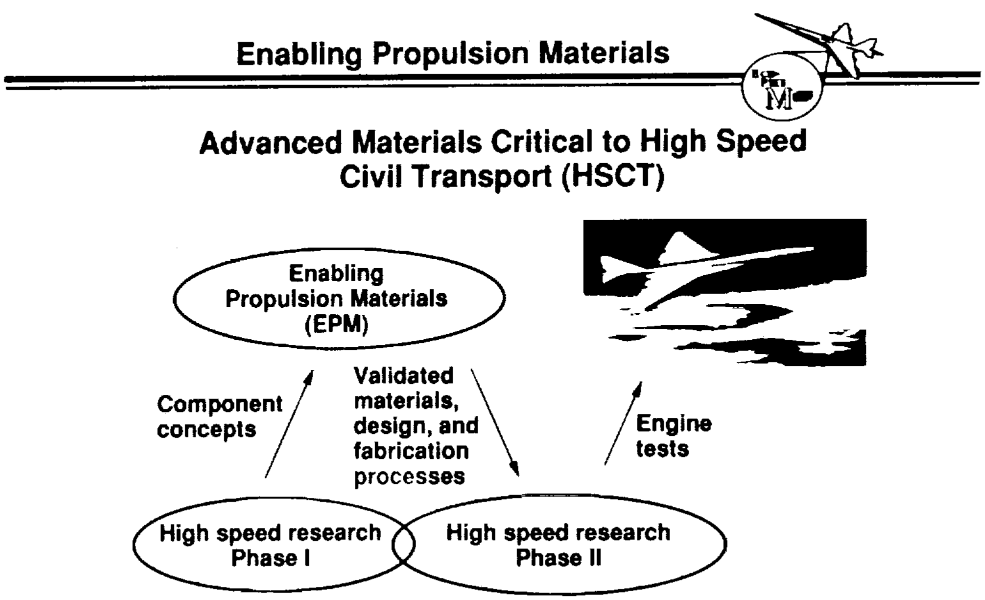


Figure 1.

REQUIREMENTS FOR A SUCCESSFUL HSR PROGRAM

The success of the next generation HSCT depends upon not only its environmental acceptability, but upon its economic viability, and technical feasibility. There is great concern internationally about the impact that a fleet of several hundred HSCTs will have on the ozone layer because of the pollutants (primarily NO_x emissions) that will be generated by the engines. Current designs indicate that an altitude of 60 000 to 70 000 ft will be optimum for the aircraft as it is now envisioned. The impact on the ozone layer is anticipated to be much greater as a result of flying at this altitude compared to today's subsonic aircraft which normally only fly at about half this altitude. This is why the combustor technology is critical to the HSCT propulsion system. Being a friendly neighbor of residential and business establishments surrounding international airports must also be addressed by meeting FAR 36 requirements. A ground rule going into the HSR Program is that the U.S. HSCT will not be government subsidized, but must be commercially economical. To meet these requirements, technical feasibility of all advanced technologies must be demonstrated. Propulsion materials are considered to be enabling to the HSCT. The engine's environmental acceptability hinges on achieving a combustor that will operate at a gas temperatures up to 3400 °F. With minimum air cooling, this dictates the need for ceramic-based materials that have not been fully developed. For a HSCT to be economically viable, light weight, up to 2400 °F temperature capability materials must be developed for the exhaust system. This arises because designs now underway suggest that the nozzle could comprise nearly 50 percent of the engine weight if constructed from materials such as high density nickel-based or cobalt-based superalloys which are used in today's commercial engines. These superalloys are the current high temperature engine materials, but their maximum use temperature is only about 2000 to 2200 °F.

Enabling Propulsion Materials

Requirements for a Successful HSR Program

- Environmental acceptability
  - Ozone layer impacts
  - Airport noise
  - Sonic boom
- Economic viability
  - Market
  - Timeliness
  - Cost
- Technical feasibility
  - Materials
  - Propulsion
  - Airframe
  - Aerodynamics
  - Flight deck and controls

Figure 2.

TECHNICAL FEASIBILITY

Propulsion materials are considered to be the highest risk area for the next generation HSCT in terms of technical feasibility. Several factors contribute to this determination. Extending the material use temperature in the combustor up to the range of 2800 to 3000 °F is considered to be the most challenging technology development facing the materials researchers and engine designers. Simultaneous with this development is the need to develop light weight, high strength-to-density materials for the nozzle that can withstand temperatures approaching 2300 to 2400 °F. It is anticipated that ceramic matrix composites and intermetallic matrix composites will be leading candidate materials for the combustor and nozzle, respectively. New fibers and fiber coatings will be required to reach these extreme use temperatures for the component lives required. In addition, fabrication of large components will rely on processing and joining concepts that currently have not been demonstrated beyond laboratory scale feasibility. Laboratory and rig testing along with analytical modeling concepts will be required to demonstrate the structural reliability and durability of these new materials.

If we consider the possible fall-back positions that exist today, it is concluded that for the 2800 to 3000 °F combustor material, there is none. Carbon-carbon composites might have the temperature capability for short military applications, however for commercial engine applications these composites will not holdup for the anticipated thousands of hours operation required. To achieve the needed structural viability and durability required for the combustor and nozzle applications, the only alternative if the goals of the program can not be met is to reduce the operating temperature by introducing cooling air. However, an unacceptably high penalty in propulsion efficiency is currently projected as a result of this approach.

Enabling Propulsion Materials

Technical Feasibility

Highest risk area:
- Propulsion materials
  - Ceramic matrix composites (CMC) required for combustor operation at 2800 - 3000 °F
  - Multiple simultaneous nozzle material developments (ceramic matrix composites, and intermetallic matrix composites)
  - Joining technology
  - Structural viability and durability (>> 4000 - hr life)

Fall-back position
  - None for 2800 - 3000 °F CMC
  - Viability/durability met through reduced operating temperature (with major performance penalty)

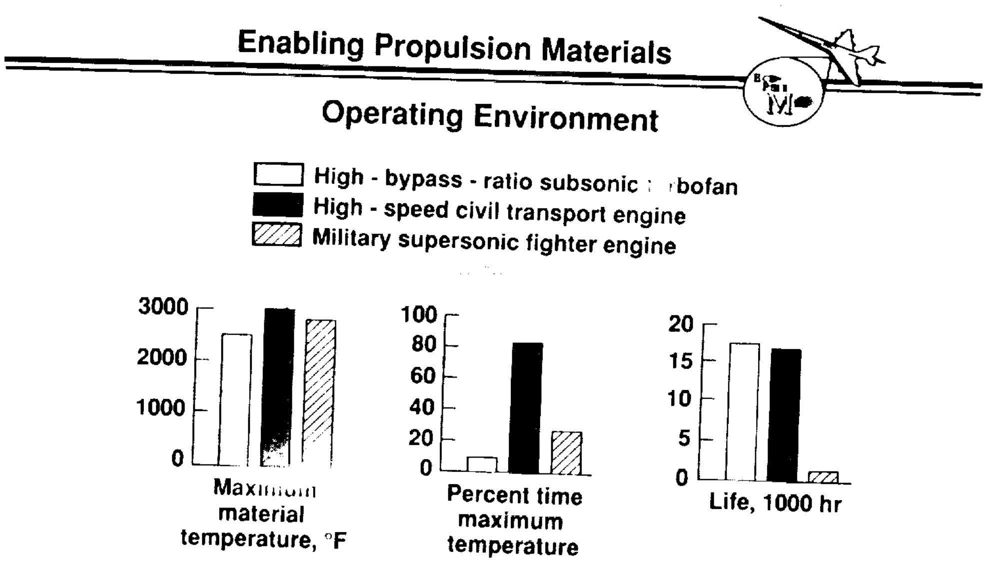
LIMITED DISTRIBUTION

Figure 3.

OPERATING ENVIRONMENT

The operating environment in terms of combined exposure to temperature and time that the propulsion materials will experience in a HSCT application is much more severe than those that now exist or are projected to exist in future subsonic and military aircraft engines. Projected materials temperatures for the three types of engines are seen to vary from about 2600 to 3000 °F with the HSCT having the highest proposed material use temperature. However, the percent time at maximum temperature is the primary factor that distinguishes the HSCT from the other types of aircraft engines. The HSCT engine will be designed to spend nearly 85 percent of its life at the maximum operating temperature compared to about 25 percent for a military fighter aircraft engine, and only around 10 percent for a typical subsonic aircraft engine. A final consideration is the time at maximum temperature that these materials will experience. For commercial engines (both the HSCT and subsonic), 18 000 hr life is a typical goal. In contrast, for military applications lives of 2000 to 4000 hr are more typical.

The engine environments described above also dictate the potential failure modes that must be taken into consideration when designing the combustor and nozzle components. Military engines typically experience frequent thermal cycling as a result of relatively short flights or an operational mode corresponding to much of the flight being at reduced power (reduced temperature) and frequent bursts of power (increase to maximum temperature) for short time periods. Fatigue failure is a major design consideration for military applications. In contrast, for commercial applications, especially for the HSCT where long times at extremely high temperatures are required, creep deformation is a primary design criterion.



LIMITED DISTRIBUTION

Figure 4.

NEW ENGINE MATERIALS INTRODUCTION STRATEGY

Because of the high risk involved in developing new higher temperature/long life materials and the long lead time required to get new materials into flight hardware, it is imperative that EPM can begin in FY'92 to meet a tentative goal of the year 2005 for the first flight of the HSCT. It is not uncommon for materials development to take from 15 to 25 years before flight hardware is realized. Laboratory research, such as being conducted under NASA's HITEMP program can typically take 7 to 10 years to demonstrate feasibility of a new material in small coupon sizes. Scale-up and characterization along with demonstrating feasibility of fabrication, joining, and manufacturing technologies for a new material can take another 7 to 10 years. The planned EPM program will fill the role in this latter phase of a material's development history. Government funding along with some industry resources are required in this phase. If at this step, industry is convinced that a market exists and the new material development can lead to an economically viable product, there will be a commitment on the part of industry to bring the technology to fruition by entering into the production phase. The time frame for EPM is thus very compressed with only 7 years available to develop and demonstrate the feasibility of high temperature composite materials for the combustor and nozzle of the HSCT.

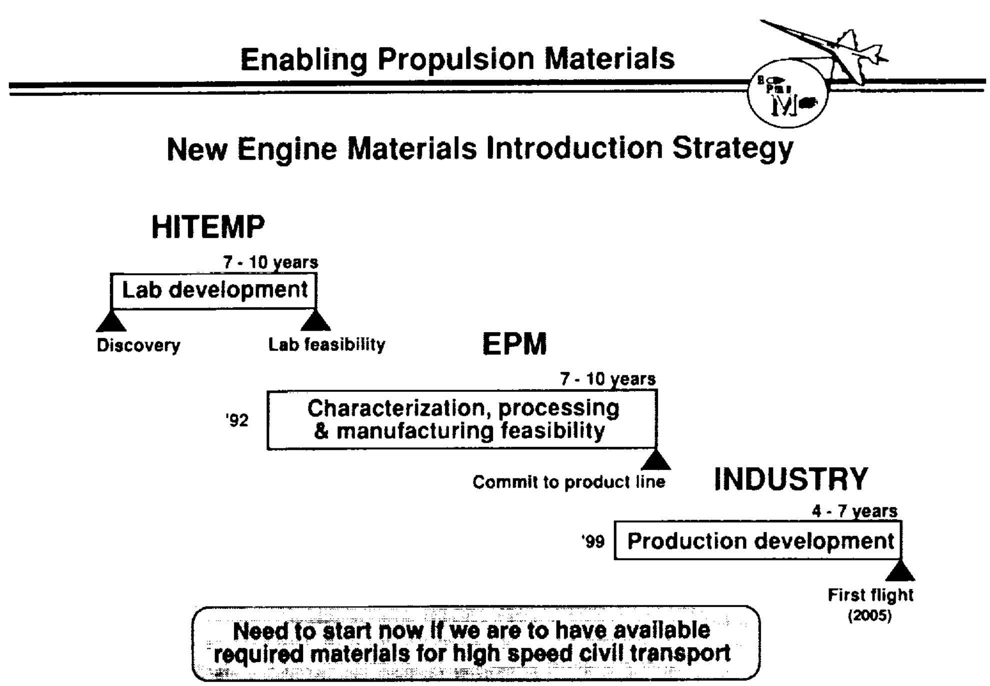


Figure 5.

ENABLING PROPULSION MATERIALS

Enabling propulsion materials are planned to be developed for the combustor and the nozzle. Ceramic matrix composites (CMCs) are the leading candidate materials for the combustor because of their light weight, environmental resistance, and potential strength at the anticipated extremely high temperatures of operation in the combustor. Successful development of CMCs will help achieve high combustion efficiency of the fuel and provide the option to design and fabricate a combustor liner that will help meet the emission (primarily NO_x) requirements of the HSCT.

Intermetallic matrix composite (IMCs) are the leading candidate materials for the nozzle where a high strength-to-weight ratio is essential to reduce the overall weight of this high temperature component. Because of the potential airport noise problem the nozzle must be quite large to combat this issue. The light weight IMCs combined, perhaps, with light weight CMCs in selected applications within the nozzle structure will also contribute to a high propulsive efficiency.

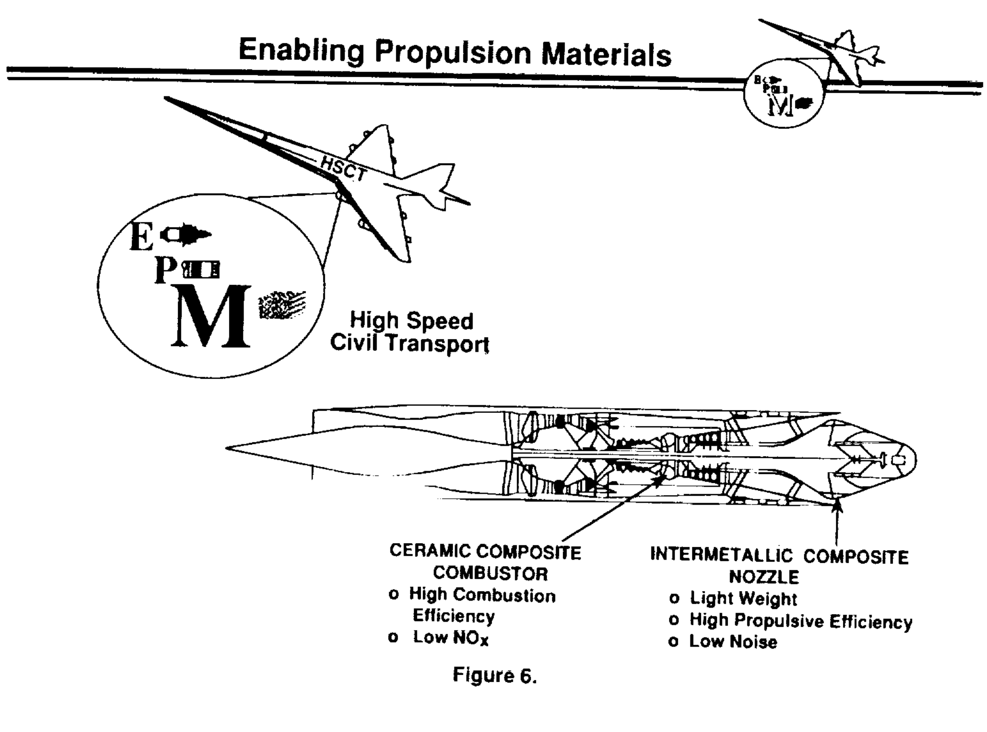


Figure 6.

OBJECTIVE

The planned EPM program will involve a large contractual effort along with key contributions from researchers at NASA Lewis Research Center. The objective is stated below:

Enabling Propulsion Materials

Objective

By 1999 develop and demonstrate in cooperation with U.S. industry, the technical feasibility of high temperature, light weight composites for critical components of the High Speed Civil Transport

Figure 7.

GOALS

The goals set for the EPM program take into account the economic viability of a commercial aircraft, environmental restrictions anticipated for such a HSCT, and the technological barriers that must be overcome to meet the goal of a first flight of a fleet of HSCTs by the year 2005.

The goal for the life of the hot section of the engine including the combustor and nozzle is 18 000 hr. This is typical for subsonic commercial engines. However, this is a very ambitious goal in the case of the HSCT where 85 to 90 percent of the 20 000 hr will be at the maximum operating temperature of the engine.

The goal for the material temperature in the combustor is up to 3000 °F. This goal is seen as very high risk primarily because of the lack of a fiber that will withstand this temperature for the long life of the engine. High conductivity ceramic matrices may permit some backside cooling to help alleviate this high material temperature need.

The goal for the material temperature in the nozzle is up to 2400 °F. Again, this is a high risk goal primarily because of the reactions that may occur between the fiber and matrix at such high temperatures and for such long times at temperature. Ceramic matrix composite nozzle liners may find use in the hotter portions of the nozzle at low stresses, while the IMCs may be used in the lower temperature, high stress regions. Both the IMCs and the CMCs can contribute significantly to reducing the weight of the nozzle in order to achieve the weight reduction goal of 30 percent compared to currently used nickel-based or cobalt-based superalloys.

Enabling Propulsion Materials

Goals

- **18,000 hours hot section life**
- **High-temperature operation**
  - **up to 3000°F for combustor**
  - **up to 2400°F for nozzle**
- **Light weight**
  - **30% weight reduction in nozzle compared to current superalloy technology. Equivalent to aircraft TOGW reduction of 2.6%**

Figure 8.

IMPACT AND APPROACH

The success of the EPM program is needed for a successful HSCT program. A successful HSCT will in turn impact the United States aerospace community by helping it remain competitive in a world market where for the HSCT, it is believed that possibly only one group will produce this aircraft. A strong technology base will help the U.S. companies retain their leadership position into the 21st century.

The overall approach to EPM consists of a planned 7 year, primarily contractual program involving a broad team effort across U.S. industry. This contract team along with contributions from NASA Lewis Research Center's Materials Division and Structures Division will develop the combustor and nozzle critical materials technologies to meet the goals of the HSCT program.

Our current plans are to be in a position to award a contract to the winning industrial team by the start of FY'92 (October 1991).

Enabling Propulsion Materials

Impact:

Retain U.S. competitiveness in world market for a supersonic transport

Approach:

- **Initiate a 7-year duration effort**
- **Involve team efforts across U.S. industry**
- **Develop combustor and nozzle critical technologies**
- **Award contract by October, 1991**

Figure 9.

TECHNOLOGY READINESS LEVEL: COMBUSTOR LINER

To appreciate the magnitude and degree of difficulty of the research and development being undertaken in the EPM program, it is appropriate to examine the current state of the art for combustor liners and to also look at activities underway on the advanced composite materials. Cobalt-based or nickel-based superalloys are used in today's engines for combustor liners and require extensive cooling to maintain even a short time material temperature limit of about 2200 ^{o}F. Revolutionary advancements in material capabilities will be required to meet the 3000 ^{o}F goal for the combustor.

Several government funded programs are underway to develop advanced CMCs for applications in gas turbine engines. The Department of Defense's Integrated High Performance Turbine Engine Technology (IHPTET) program is evaluating oxide-oxide CMCs for lower temperature applications. NASA's Advanced High Temperature Engine Materials Technology Program (HITEMP) has both in-house and contractual efforts underway to develop higher temperature fibers for temperatures approaching 3000 ^{o}F, addressing various processing/fabrication alternatives for CMCs that may be adaptable to combustor manufacturing technology, and has a cooperative program now underway with industry to identify and characterize on a laboratory scale, potential candidate materials for the combustor.

Enabling Propulsion Materials

TECHNOLOGY READINESS LEVEL: Combustor liner

STATE OF THE ART: Cobalt base and nickel base superalloys limited to 2200 °F and require excessive cooling

- **Oxide-Oxide: 1800 °F CMCs under evaluation (IHPTET)**
- **Candidate high-temperature fibers to 3000 °F (HITEMP)**
- **Processing/fabrication of CMCs underway (HITEMP)**
- **Candidate CMC fibers/composites for combustor liners (NRA contract)**

Figure 10.

STRESS RELAXATION TEST DEVELOPED TO RANK CREEP RESISTANCE OF SiC FIBERS

There is a need for creep resistant fibers to meet the demand of very long times at temperatures approaching 3000 °F for the combustor. A method has been developed that permits the rapid evaluation of candidate fibers in controlled environments. The approach is to measure the fiber stress relaxation in a bend or loop test which in turn can be related to the creep resistance of the fiber. Bend stress relaxation has been determined for different types of nonoxide fibers between 1850 and 2550 °F. This test has been used to rank the creep resistance of various commercial and developmental fibers under similar test conditions. The results were correlated to the tensile creep behavior of the SCS-6 fiber and results were found to be give excellent correlation between the two methods. It is concluded that all of the polycrystalline fibers tested relaxed (crept) at 2550 °F while the single crystal SiC whisker showed no stress relaxation or creep deformation at this temperature.

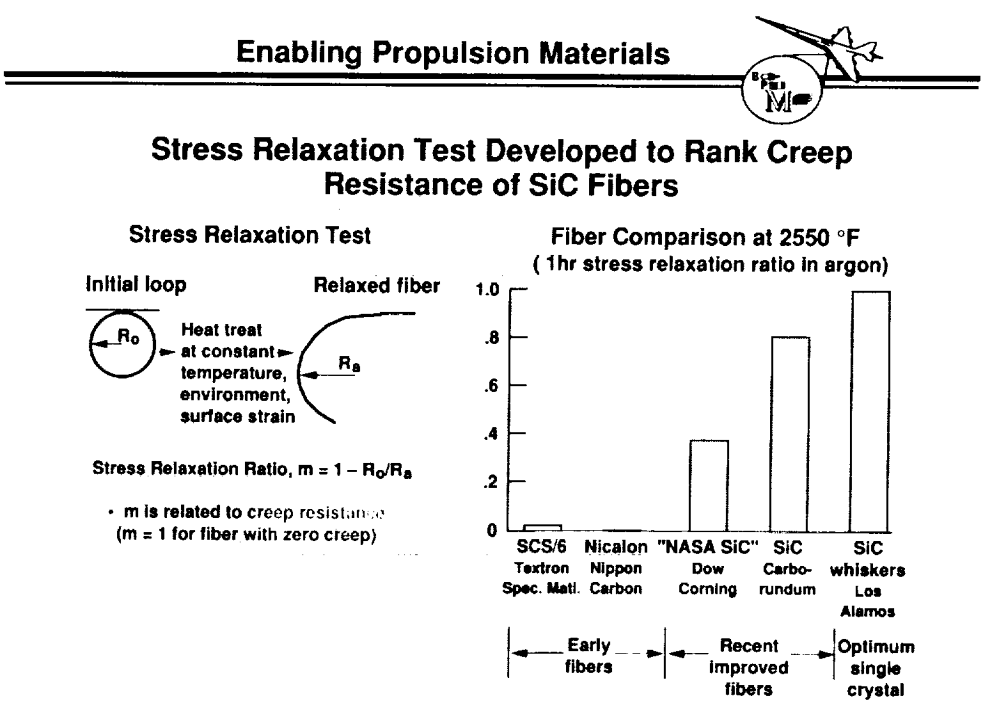


Figure 11.

MAXIMUM USE TEMPERATURE FOR CANDIDATE COMBUSTOR MATERIALS

A major issue in the development of the HSCT combustor is the selection of materials to withstand the harsh combustion environments. Predictive modeling has been undertaken to approach this issue and involves an understanding of the key interactions between the combustion environment and candidate materials. The current candidate materials include silicon-base ceramics as structural materials and oxide base-ceramics as coatings. The key interactions include volatility, oxidation, and interfacial reactions. The volatility issue has been addressed by modeling the combustor as a hollow cylinder with walls that vaporize through a boundary layer. A limiting criterion for the use of any material was established to be 10-mils of material lost in 10 000 hr. Therefore, minimum acceptable vapor pressures were established that could be related to maximum use temperature through the predictive models. These maximum use temperatures are presented for some candidate combustor liner materials.

The oxidation and interfacial reaction issues related to material lifetimes are more difficult to quantify and, as of yet, have not been modeled. Experiments will be performed to gain experience with such effects as water vapor and thermal cycling on the oxidation behavior of silicon-base materials.

Enabling Propulsion Materials

Maximum Use Temperatures for Candidate Combustor Materials

Limiting Criterion: 10 mil/10,000 hr Material Loss

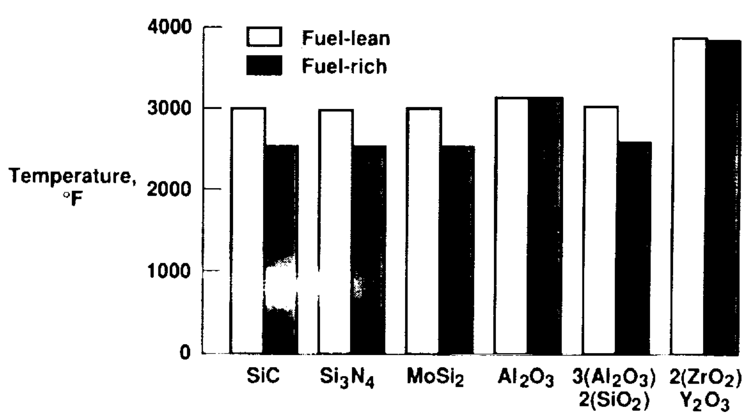


Figure 12.

FRCMC TESTING IN ROCKET ENGINE ENVIRONMENTS

Progress is being made in the research and development of CMCs for applications in rocket engine environments. Although times at temperature are extremely short compared to commercial gas turbine engine applications, the experience gained in fabrication various components will be invaluable in the initial steps of scaling up the CMCs for the combustor. In addition to small laboratory scale coupons, such components as nozzle/combustor chambers and turbine blades have been fabricated for rig testing. Plans call for full scale testing of these fiber reinforced CMCs components in a ground-based test bed turbopump of the type (but smaller than that) used on the space shuttle main engine (SSME) in 1995.

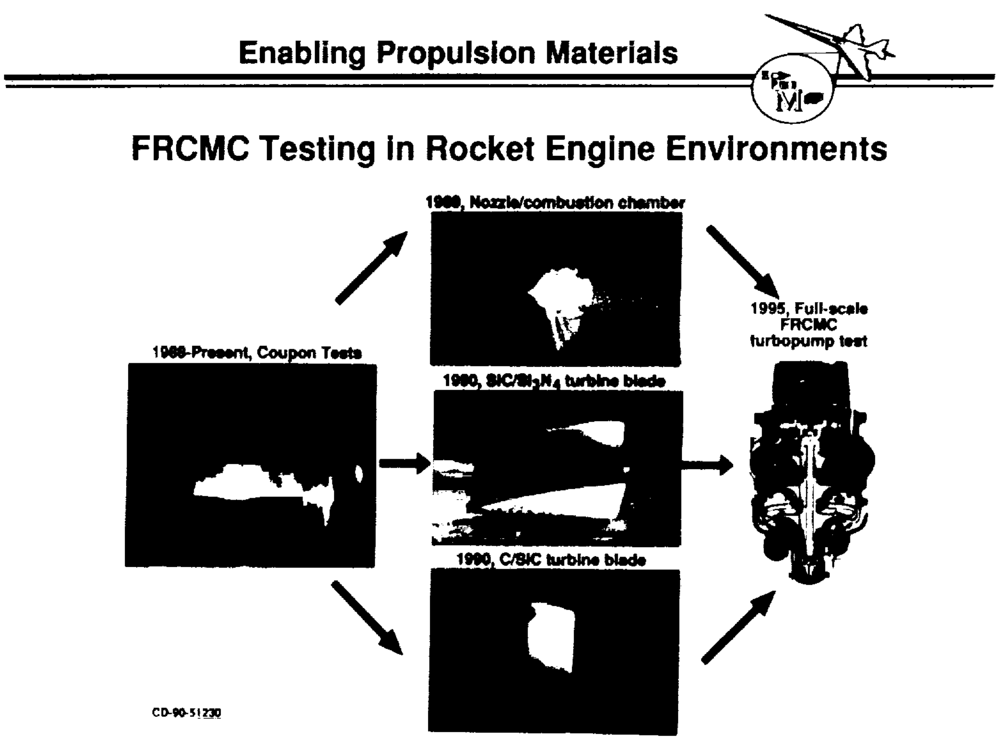


Figure 13.

REQUIRED TECHNOLOGY DEVELOPMENT FOR COMBUSTOR LINER

Based on the current state-of-the-art, technologies that need to be addressed in EPM run the gamut from identifying promising constituents of the composite materials to the final fabrication of a full-scale combustor liner for ground base engine testing. One of the major barriers that must be overcome is that of a high temperature fiber (and its coating) that can maintain its stability and properties to meet the goals of EPM. Laboratory test on candidate fibers to characterize their behavior under simulated HSCT conditions must be performed to rank the fibers and select those that have the best potential for subsequent composite processing. Fiber matrix compatibility to achieve the proper bond for long term, optimum performance is also a major consideration. Composite durability and environmental resistance in simulated combustor environments and the prediction of their failure mechanisms and life will have to be evaluated for these advanced materials. Finally, after laboratory characterization, benchmark testing, and model validation, the next challenge is to scale-up the fiber and composite fabrication processes and learn how to design, fabricate and test components or subcomponents manufactured from the advanced composites.

Enabling Propulsion Materials

Required Technology Development For Combustor Liner

- **Fiber development and characterization to 3000 °F**
- **Fiber-matrix compatibility for optimum performance**
- **Scalable fabrication process**
- **Composite materials durability and environmental resistance**
- **Life prediction methodology for CMCs**
- **Design, fabrication, and test verification of CMC combustor liner component**

LIMITED DISTRIBUTION

Figure 14.

TECHNOLOGY READINESS LEVEL: NOZZLE STRUCTURES

Exhaust nozzle technology today relies on nickel-based superalloys with thermal barrier coatings. These materials are possible materials of construction for the proposed nozzle designs for the HSCT. However, because of the extremely large size of the proposed nozzle to meet noise regulations and high propulsive efficiency, the weight of the nozzle fabricated from superalloys will constitute a major portion of the total engine weight. Engine weight increases produce highly accentuated structural weight increases with major reductions in aircraft range or passenger capacity. Therefore, lighter weight, high-strength-to-density materials are required to meet the performance requirements of the HSCT. Intermetallic matrix composites are leading candidate materials for this application since they have a density less than two-thirds that of the nickel-based superalloys. The HITEMP program is pursuing IMCs for high temperature applications comparable to that proposed in the nozzle application of the HSCT. In addition, experience is being gained under the IHPTET program to develop intermetallics for turbine blade applications which should strengthen the data base on these materials and give more confidence as the advanced composites are developed.

Enabling Propulsion Materials

TECHNOLOGY READINESS LEVEL: Nozzle Structures

STATE OF THE ART: Nickel base superalloys with thermal barrier coatings impose large weight penalty

- **IMC development to 2400 °F (Industry IR&D, HITEMP)**
- **IMC turbine blade development (IHPTET)**

Figure 15.

REQUIRED TECHNOLOGY DEVELOPMENT FOR EXHAUST NOZZLE STRUCTURE

Similar technologies need to be explored and developed for the advanced composites for the nozzle as were described for the combustor. In particular, fiber technology is a major barrier that must be addressed. Ceramic fibers are leading candidates because of their light weight and temperature capability. Intermetallic matrices such as nickel aluminide are being considered because of their low density and potential capability in terms of environmental resistance at the temperatures proposed for the nozzle. A major barrier to be overcome is the difference in coefficient of thermal expansion (CTE) between ceramic fibers which is typically low and that of the intermetallics which is quite high on a comparative basis. Compliant layers or graded coatings on the fibers will be explored as possible methods of achieving improved CTE matching and thus increasing the life that is required of the fiber-matrix interface without degradation of the composite. Composite processing, characterization, and life prediction will play a major role for the advanced composite under development for the nozzle application. Subsequent scale-up, fabrication, and subcomponent evaluation in rig and possibly engine tests will further be required.

Enabling Propulsion Materials

Required Technology Development for Exhaust Nozzle Structure

- Fiber selection and coating development to 2400°F
- Composite material processing and characterization
- Life prediction methodology for IMCs/CMCs
- Design, fabrication, and test verification of lightweight IMC nozzle structure prototype components and CMC liner

LIMITED DISTRIBUTION

Figure 16.

PROJECT LOGIC

The EPM program logic will evolve from the selection of an engine concept in the initial phase of the program to final delivery of components and subcomponents in the program's final phase. An annual materials capability-design trade-off study will be performed to define property goals for the composite development and to assure that the research and development stays on track for the HSR Phase II program so that the goals set for the HSCT will be met. The deliverables from the combustor phase of the program are two combustor liners for evaluation in the planned HSR Phase II program. The nozzle portion of the program will develop subcomponents to be evaluated in rig tests or "piggy back" engine tests in another engine that may be available at the time.

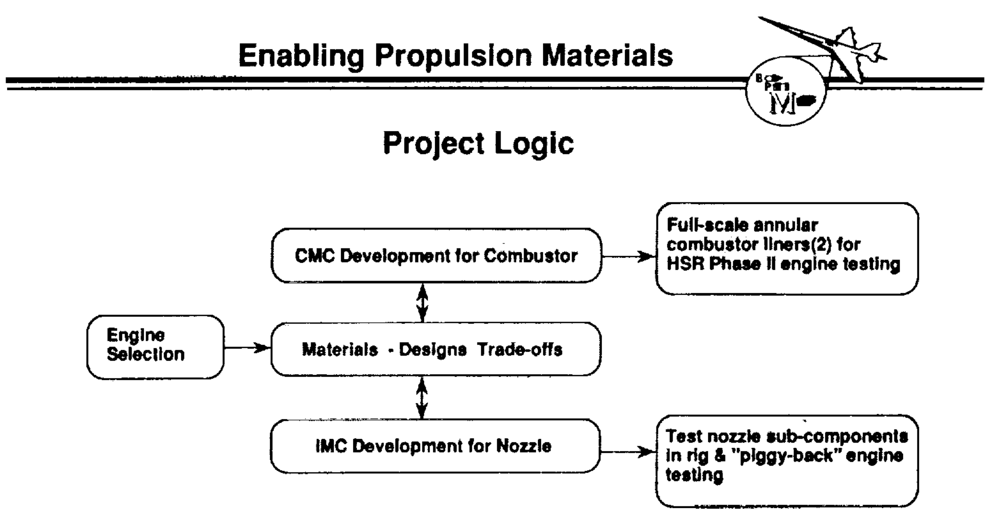


Figure 17.

CONCEPT SELECTION

The engine concept selection will be followed by design activities to demonstrate the benefits of the advanced materials. This will involve conceptual designs using state-of-the-art, 1991 technology. Since there are two combustor concepts that are under consideration, one engine design will be with the rich burn, quick quench, lean burn (RQL) combustor while another engine design will be with a lean burn premixed prevaporized (LPP) combustor. There are also two nozzle concepts under consideration which include a two-dimensional concept and an axisymmetric concept. Therefore, one or the other of these nozzle concepts will be selected for the RQL combustor and one or the other for the LPP combustor. This procedure will be repeated using projected 1999 technology. Based on these engine design studies, payoffs in terms of take-off gross weight (TOGW), fuel burned, and cost as a result of using the advanced composite materials can be shown.

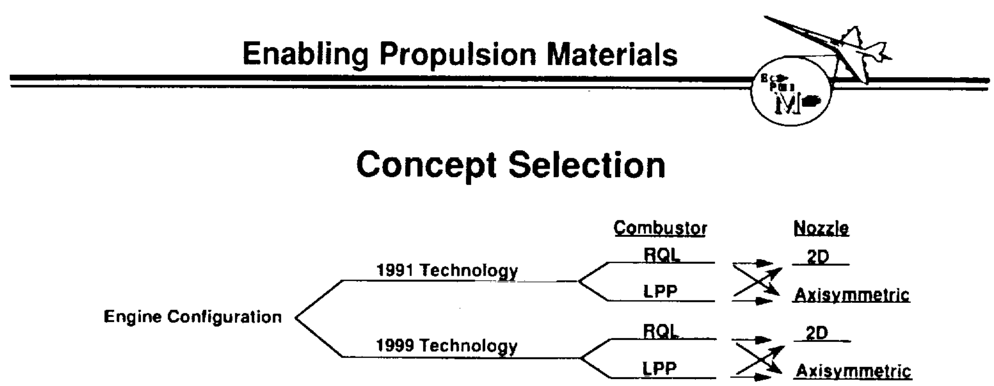


Figure 18.

TASK SCOPE

Materials and analytical modeling development constitute the heart of the planned EPM contractual program. The engine and component design trade-offs will provide guidance to the development of the materials with properties meeting the goals required for the HSCT. As described previously, fiber development and identification of appropriate coatings for the individual fibers will be addressed for both the combustor and nozzle materials. High strength and high temperature stability will be primary factors to be explored. In addition, compatibility with the candidate matrices and environmental durability must be established for the proposed use temperatures and times.

Scale-up of the fiber processing and composite fabrication techniques will be required in order to ultimately be able to fabricate the combustor liner and nozzle subcomponents. Joining techniques for similar and dissimilar materials will be optimized for the CMCs and IMCs selected for component fabrication. Success in this area of the program will permit advancing promising composite materials from the laboratory scale coupons to large panels for benchmark testing.

Characterization of the advanced composites developed in the EPM program will be guided by the operating conditions anticipated in the combustor and the nozzle. Laboratory testing and subsequent rig testing will simulate the temperature, time, pressure, cycles, and environmental conditions imposed by the HSCT.

Parallel to the material development, process modeling will aid in the growth of fibers and optimization of composite fabrication techniques. Structural modeling will focus on failure mechanisms and life prediction of the composite materials. This in turn will be applied to the component and subcomponent fabrication and subsequent life predictions for rig and engine testing.

Enabling Propulsion Materials

TASK SCOPE

Combustor & Nozzle Materials & Modeling Development Constitute the heart of the EPM Program

• Fiber Development	- High strength & high temperature capability, compatibility, and durability are key fiber issues to be addressed.
• Materials Development	- Fabrication, scale-up, and joining of composites from laboratory coupons to engine components is a major technology barrier that must be overcome.
• Materials Characterization	- Materials will be characterized under simulated HSCT combustor and nozzle environments with emphasis on life, failure modes, and mechanical properties.
• Analytical Modeling/Verification	- Structural modeling and verification will aid in materials development and prediction of component behavior.

Major Deliverables: Ceramic matrix composite(s) and appropriate models for combustor and nozzle liner design/fab/life prediction.

Intermetallic matrix composite and appropriate model for nozzle structure design/fab/life prediction.

Figure 19.

PROGRAM SUMMARY

The program is summarized in terms of four activities. They include CMC material development and liner fabrication for the combustor and IMC materials development and subcomponent fabrication for the nozzle.

Key milestones for the combustor materials development include identification of fibers for scale-up, demonstration of composite fabrication techniques, demonstration of the 18 000 hr durability for the primary CMC in a laboratory rig test, and post engine test evaluation of the CMC liner.

Two key milestones for the combustor liner fabrication include the delivery of liner sectors and ultimately the combustor liners to the HSR Phase II program for test under simulated and actual engine testing.

Milestones for the IMC materials development include selecting a fiber-coating-matrix combination for scale-up, demonstration of subcomponent fabrication, and post test evaluation of a subcomponent fabricated from an IMC (and possibly a CMC liner) and tested in a rig and possibly an engine.

The key milestone for the nozzle fabrication phase of the program is to test a subcomponent.

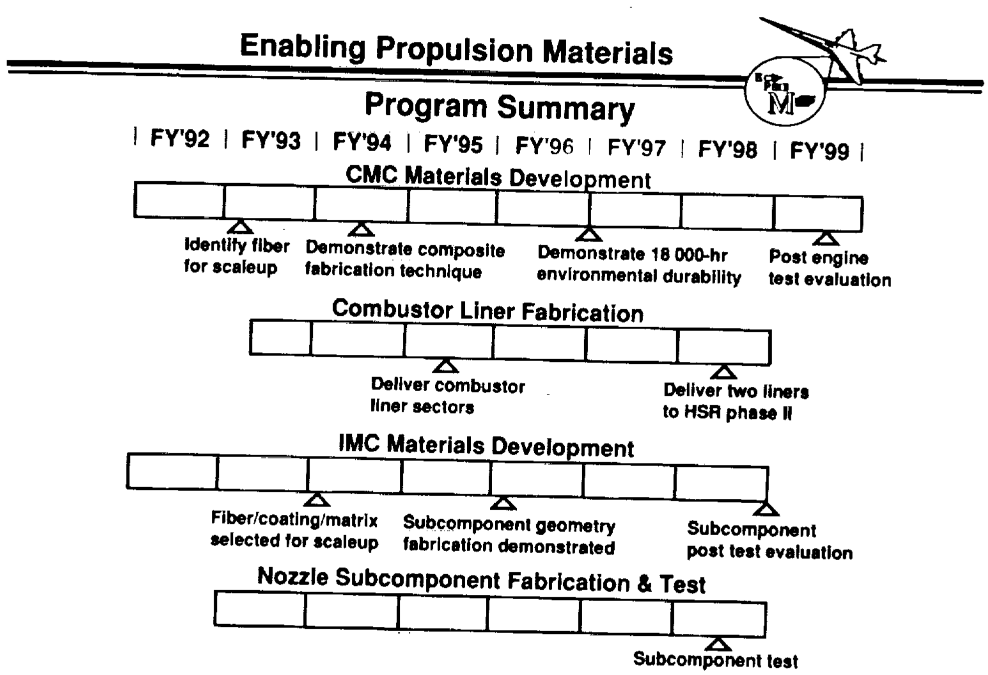


Figure 20.

PROJECT ORGANIZATION

The EPM project is organized such that Lewis Research Center has the direct management of the planned contractual research and development. An advisory team made up of cognizant representatives from industry will be selected to assure that the materials development is directly focused on the needs of the HSCT and is compatible with the HSR Phase II program.

It is anticipated that an industrial team will form the basis for the contractual program. Because of the complexity of the materials development and the high risk involved technically and economically, contributions from several engine companies, fiber producers, composite fabricators, material and equipment manufactures, and academia where appropriate, will be required to enhance the potential of making this program a success.

NASA Lewis will not only have overall management responsibility of the contractual program, but will conduct in-house research in support of the contractual effort. In-house research will focus on filling gaps that may occur in the contract program and providing alternatives to those area that are considered the highest risk areas technically.

Along with the mainstream of research, NASA plans to periodically issue NASA Research Announcements (NRAs) that will provide opportunities for those not directly involved in EPM to propose new ideas and alternatives for consideration by the Project. If any new ideas prove to be promising, they will be factored into the EPM effort by incorporating the originating organization into the team membership or by some other mechanism.

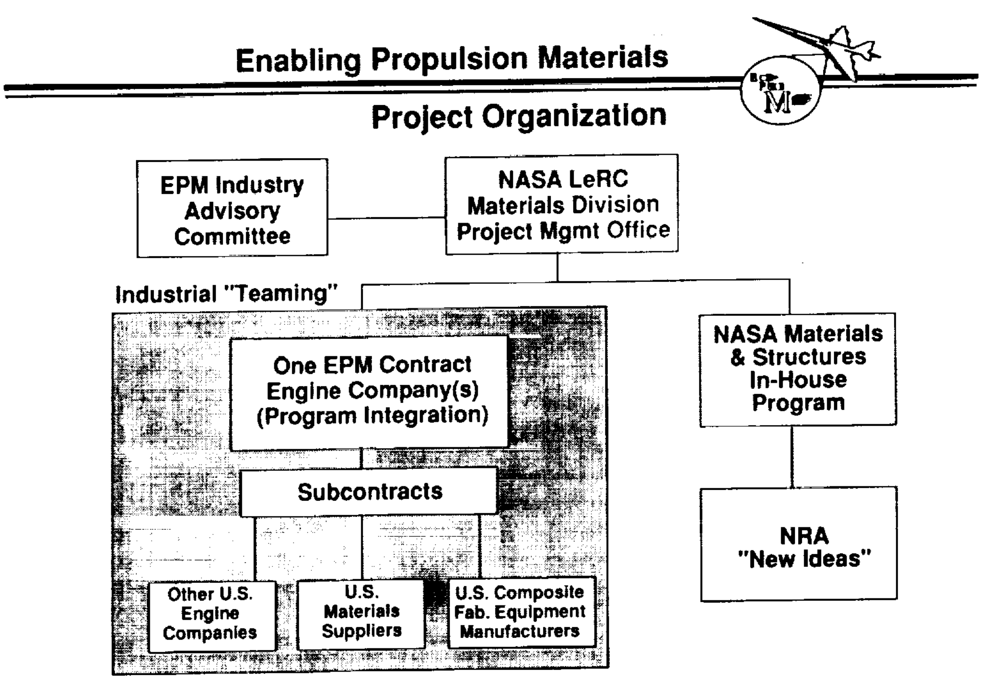


Figure 21.

EPM INDUSTRY TEAM APPROACH

Anticipated roles of the team members as well as NASA Lewis are delineated herein.

The engine companies will provide the program integration, materials/component design trade-offs, design methods and fabrication requirements of the components, and component/subcomponent testing in appropriate rigs and engines.

Materials suppliers will play a key role in the overall success of the EPM program. Fiber producers will be called on to develop advanced fibers and appropriate coatings. Matrix materials will have to be supplied that have the desired environmental resistance and are compatible with the fiber/coating combination. The program will look to these organizations to develop fabrication techniques that will enable the manufacture of the subcomponents and components.

Other organizations whose expertise may be required to successfully meet the demands of the program include those who can provide net shape fabrication, two-dimensional and three-dimensional weaving capabilities, and specialized processing and joining capabilities.

NASA Lewis Research Center will provide the overall project management, selected material characterization, some new material concepts, and life prediction and test methods where appropriate.

Enabling Propulsion Materials

EPM Industry Team Approach

Engine Companies
- Program Integration
- Materials/component design tradeoffs
- Design methods and fabrication
- Component tests

Materials suppliers
- Fibers and coatings
- Matrix Materials
- Process and composite fabrication

Other Companies
- Net shape fabrication
- 2D & 3D weaving
- Processing and joining

NASA Lewis
- Project management
- Material characterization
- New material concepts
- Life prediction and test methods

Figure 22.

SUMMARY

It is has been established that advanced materials are key to the environmental acceptability of a 21st century HSCT. In particular, advanced materials are enabling for the combustor, primarily to control NO_x emissions to acceptable levels and for the exhaust nozzle to significantly reduce the weight and thus have a direct impact on the economic viability of the aircraft.

Because of the long lead time required to develop advanced materials, EPM is planned to start 1 year ahead of the rest of the HSR Phase II program. Even with this head start, the 7-year research and development program is an extremely tight schedule considering the current state-of-the-art of high temperature composites, and the rigorous temperature/life requirements for success.

NASA has initiated some exploratory contractual and in-house efforts to help define the scope of the technology to be undertaken in the EPM program and is proceeding with the necessary procurement steps to be in a position to initiate the contractual program beginning in FY'92 assuming that budget approval is obtained.

Enabling Propulsion Materials

Summary

- **Advanced materials are key to a low-NO_x combustor and a lightweight nozzle for the HSCT engine.**
- **An extremely tight schedule is required to meet technology readiness goals for 1999.**
- **NASA has initiated contract and in-house research to address critical materials needs and has issued a request for proposals for a 7-year Enabling Propulsion Materials contractual program to accomplish the required technology needs.**

Figure 23.